# Spin Asymmetries of the Nucleon Experiment

(PR03-002)

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**Outline**

- Spin structure
- Why high *x?*
- Measured Asymmetries
- Extracting $A_{1p}$ and $g_2$
- Projected Results
- Summary



# Spin Structure

Deep Inelastic lepton scattering data has yielded wealth of knowledge of nucleon structure. Quark distributions inside nucleon are described by four structure functions

- Structure functions: $F_1$, $F_2$ - cross section
- Spin Structure Functions: $g_1$, $g_2$ - polarization observables

In Quark-Parton Model, we can write $F_1$ and $g_1$ in terms of helicity dependent quark distribution functions, $q_i^{\pm}(x)$:

$$F_1(x) = \frac{1}{2}\sum_i e_i^2 [q_i^+ + q_i^-]$$

$$g_1(x) = \frac{1}{2}\sum_i e_i^2 [q_i^+ - q_i^-]$$

$Q^2$ dependence follows QCD-based evolution of DGLAP.



# $g_2$

$g_2(x,Q^2)$ does not have as simple an interpretation as $g_1$:

$$g_2 = g_2^{ww} + \overline{g_2}$$

$g_2^{ww}$ depends only on $g_1$ (twist 2):

$$g_2^{ww} = -g_1 + \int_0^1 g_1(y, Q^2)/y \, dy$$

$\overline{g_2}$ vanishes when all twist-3 ($d_n$) matrix elements vanish in **O**perator **P**roduct **E**xpansion (OPE), e.g.

$$d_2 = 3\int_0^1 x^2 \overline{g_2}(x, Q^2)\, dx$$



# $g_1, g_2 \leftrightarrow A_1, A_2$

The spin structure functions $g_1$ and $g_2$ are related to the asymmetries $A_1$ and $A_2$ by:

$$A_1 = \frac{\sigma_{1/2}^T - \sigma_{3/2}^T}{\sigma_{1/2}^T + \sigma_{3/2}^T} = \frac{1}{F_1}(g_1 - \gamma^2 g_2)$$

$$A_2 = \frac{2\sigma_{LT}}{\sigma_{1/2}^T + \sigma_{3/2}^T} = \frac{\gamma}{F_1}(g_1 + g_2)$$

$\gamma = 2Mx/Q$

Total photon nucleon helicity

Thus $A_1$ and $A_2$ depend on $F_1$, which helps to reduce the $Q_2$ dependence of these asymmetries.

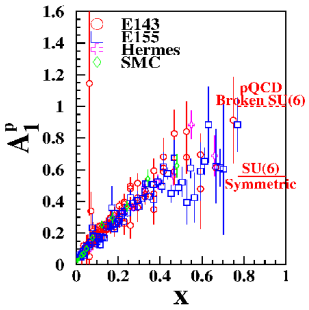
# Why High $x$?

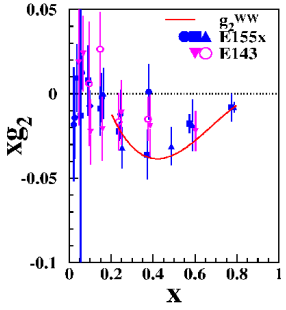
$$x = Q^2/2M\nu$$

- Understanding higher order moments to compare to Lattice QCD and QCD predictions.
- Higher twist effects become more significant at higher x.
- Examine predictions of $x \to 1$ of $A_{1p}$ of pQCD and SU(6) models:
  - SU(6) symmetric $A_{1p} \to 5/9$,
  - SU(6) broken and pQCD predicts $A_{1p} \to 1$, but different reasons.
- Region in which sea quarks play only minor role .
- Existing data at large $x$ is limited compared to lower $x$ region.
- Need better data to better understand extrapolation to $x \to 1$.



# World's Data at High x



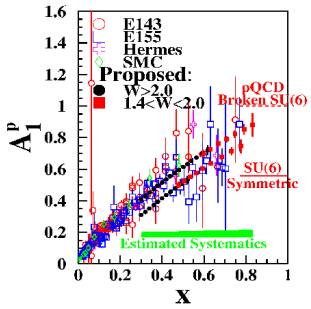



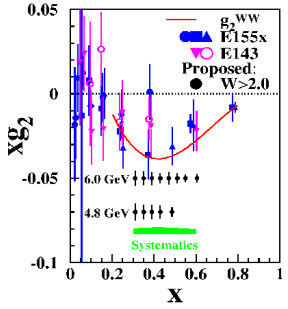

- Dominated by $NH_3$ experiments.
- CLAS data under analysis.
- Determined mostly by $A_{\parallel}$

- **$g_2^{WW}$ is twist 2 - from $g_1$.**
- **Significant uncertainty at x~0.4**
- Necessary to measure $A_{\perp}$



# World and Projected Data




For Jlab Energies, $A_{\parallel}$ and $A_{\perp}$ are necessary to extract $A_{1p}$ and $g_2$ in a model independent way



# Extraction

Measure inclusive beam-target asymmetries with polarized electron beam and polarized proton target.

For a target field orientation w.r.t. the beam $\theta_N$ the measured asymmetry is related to $A_1$ and $A_2$ by:

$$A_{meas}(\theta_N) = \alpha A_1[\ \cos(\theta_N) - \rho \sin(\theta_N)] + \beta A_2[\rho \cos(\theta_N) + \ \sin(\theta_N)]$$

$\alpha = \alpha(E,E',\theta,R)$
$\beta = \beta(E,E',\theta,R)$
$\rho = \rho(E,E',\theta)$

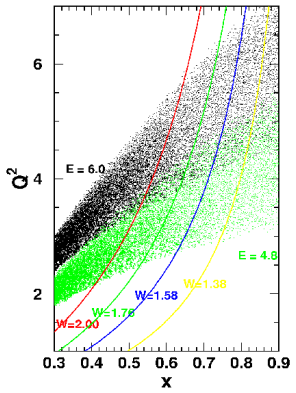
By measuring the beam-target asymmetry for two values of $\theta_N$, we can extract $A_1$ and $A_2$.

- Most sensitive to $A_1$ for $\theta_N = \theta_q$
- Most sensitive to $A_2$ for $\theta_N \approx 90^\circ$

Geometry of target magnet prevents 90° measurement, instead we will use 180° and 80°.

# Two Beam Energies

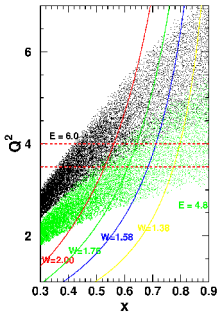
- We propose to take measurements at 4.8 and 6.0 GeV beam energies because:
- Provides limited test of local duality for spin observables. If demonstrated, then can significantly extend maximum $x$ for $A_{1p}$.
- Study $Q^2$ dependence for constant $x$.
- Study $x$ dependence for constant $Q^2$.

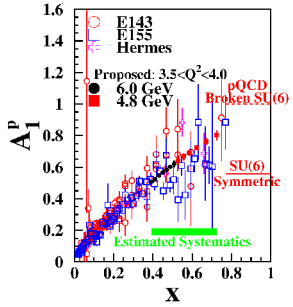





# Example of x Dependence Study

Do a $3.5<Q^2<4.0$ cut and look at $A_{1p}$ statistics:





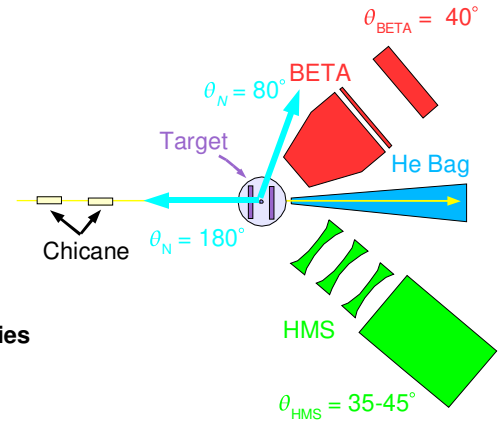

# Experimental Setup

**Target**
- UVa NH3 target
- 5 T field

**Beamline**
- Chicanes
- SEM
- He Bag

**Electron Arm**
- BETA

**Background Studies**
- HMS



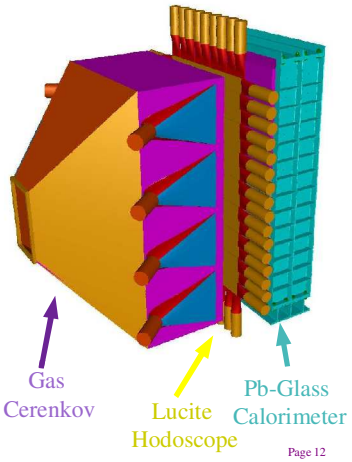



# Big Electron Telescope Array (BETA)

Gas Cerenkov
- Particle Identification
- Minimal knock-on

Lucite Cerenkov
- Redundant PID
- Tracking

Pb-Glass Calorimeter
- Calorimetry
- Hadron reduction



# Gas Cerenkov

$N_2$ Gas

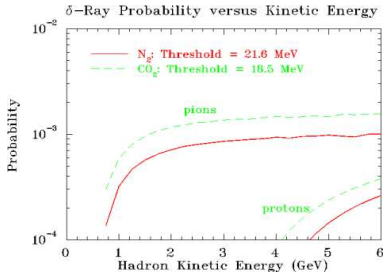
- Reduced knock-on's
- At STP, pion threshold is 5.8 GeV/c

Point-to-Point focusing

- Easy alignment of mirrors
- Further reduction of background

PMTs

- 8 Mirrors and PMTs
- Baffled
- Apply tight electron cuts
- Expected 17-20 photoelectrons






# Sytematics

Calorimeter Gains:

- Calibrated with proton elastics (using HMS in coincidence).
- Monitored through Lucite light system, cosmics and punch-through pions.

Background:

- Dominated by charge-symmetric processes, mostly $\pi^0 \rightarrow \gamma e^+ e^-$.
- Measured in HMS.
- Hadron backgrounds measured by ignoring Gas Cerenkov in trigger.



# Estimated Systematics for 6 GeV

| | |
|---|---|
| Radiative Corrections | 1.5% |
| Dilution Factor | 2.0% |
| Target Polarization | 2.5% |
| Beam Polarization | 1.0% |
| Nitrogen Correction | 0.4% |

| | A1p | | g2 | |
|---|---|---|---|---|
| | *x*=0.3 | *x*=0.6 | *x*=0.3 | *x*=0.6 |
| *R* | 2.4% | 1.8% | 4.3% | 2.5% |
| Kinematics | 0.3% | 0.3% | 3.1% | 3.6% |
| Background | 5.7% | 3.0% | 5.7% | 3.0% |
| Local | 4.7% | 3.2% | 5.8% | 4.3% |
| Global | 5.5% | 4.2% | 6.4% | 5.1% |
| Total | 7.2% | 5.1% | 8.6% | 6.5% |

Systematics for 4.8 GeV are very similar



# Beam Time request

| | | | | |
|---|---|---|---|---|
| | 6.0 | 80 | 75 | |
| | 4.8 | 180 | 170 | |
| | 4.8 | 80 | 30 | |
| | 2.4 | - | 50 | |
| **Systematics** | Packing Fraction | | 20 | |
| | Mollers | | 25 | |
| | Total beam time | | 695 | (29 d) |
| **Overhead** | Anneals | | 75 | |
| | Energy Change | | 48 | |
| | Target Rotation | | 48 | |
| | Stick Changes | | 48 | |
| | Total Overhead | | 219 | (9 d) |

# Collaboration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Spin Structure Physics
→ JLab, Temple, UVa,W&M

Detectors
→ Yerevan, LA Tech, JLab

Calorimeter
→ Protvino

Target
→ UVa



# Summary

SANE : Spin Asymmetries of the Nucleon Experiment

Physics:

- Significant improvement in $A_{1p}$ and $g_2$ in DIS at high $x$.
- Expansive study of $x$ and $Q^2$ dependence.
- Limited test of local duality.
- Simultaneously collect data in resonance region. Important for study of moments.
- Proposed next logical step in proton spin structure at high $x$.

BETA

- Designed to handle high rates of low energy background.
- Provides proof of principle for Son Of BETA (SOB) calorimeter system for 12 GeV upgrade.
- As commented in TAC, BETA could open the possibility to other exclusive and semi-inclusive measurements.

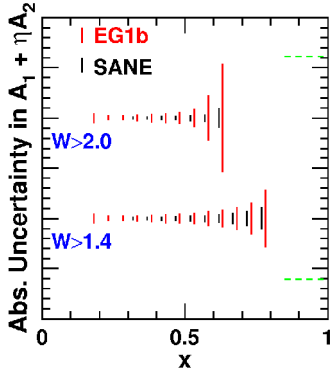




# EG1b and SANE - $A_{||}$

*Projected* statistics for SANE vs *estimated* statistics for EG1b for E = 5.6 – 5.7 GeV runs.

At this time, CLAS cannot be used to measure $A_{\perp}$. EG1b cannot extract $A_1$ without a model.

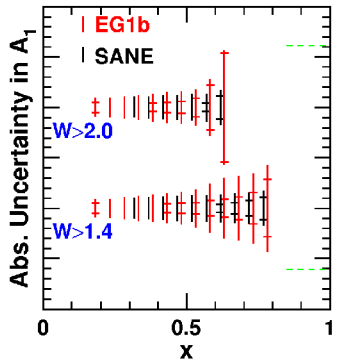


# EG1b vs SANE - $A_1$

Add point-to-point systematic errors to statistics to estimate uncertainties in $A_1$ for local fits to data.

For EG1b:

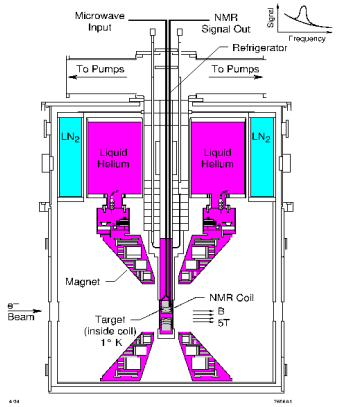
- Assume same systematics as SANE.
- $A_2$ subtraction:
  - → For DIS: 3% uncertainty.
  - → For Resonance Region: Only quality data is from E01-006 (RSS) at $Q^2$=1.3. Guess 7% uncertainty, based on Soffer limit.






# UVa Polarized Target

- Dynamic Nuclear Polarization
- 5 T Field
  - can steer beam
  - affect optics of scattered electrons
- 1 K evaporative refrigerator
- Composite target: N+H+He
  - asymmetry is diluted by unpolarized materials
- Measure target polarization
  - calibration: thermal equilibrium
  - monitoring: NMR






# Technical Comments, part I

1) Overhead of 219 hours (9 days) has not been included in the beam time request. Additional survey time for beam line chicane changes has also not been included.

   Gen01 (E93-026) ran with a 40% macroscopic efficiency, which is production ND3 time to calendar time. For SANE, once one factors in the additional 8% time requested for packing fraction and Moller measurements, we almost achieve the nominal 50% experiment efficiency.

   Most if not all of the survey time for the chicane surveys is included in the time to rotate the target and the time to change beam energies.

2) This is a large installation experiment, albeit a standard one requiring the polarized target and associated beam line chicane. Installation time has not been included, and is estimated to be 2-3 months. Deinstallation is estimated to be one month.

3) Strong technical support is assumed from the JLab Target Group for the installation, calibration, and operation of the polarized target.



# Technical Comments, part II

4) Compared to the Gep-III calorimeter, this experiment adds the requirement of gain monitoring. The plans outlined in this proposal can be accomodated into the present designs for this calorimeter. The detector package is further augmented by a gas cerenkov and a lucite detector for particle identification. The experiment heavily relies on the rejection of pions using the gas cerenkov. The required rejection factor is agressive, but may be achievable at the cost of some electron inefficiency.

   Excellent pion rejection is a matter of good design and quality control. It is not a matter of new invention. For the x>1 analysis, John Arrington found a 500:1 rejection in the HMS Cerenkov. He was able to predict this level of rejection using the same analytic expressions and figures as in our proposal. Considering the amount of material in front of the HMS gas Cerenkov, there is nothing controversial about our goal of 1000:1. Even at 500:1, the experiment still works.

5) The experiment takes advantage of the magnetic field, used to polarize the target, to eliminate background from low-energy charged particles. The Monte Carlo used to estimate these backgrounds seems realistic.

6) If this technique is proven to work, it may have a large impact on (presumably easier) semi-inclusive and exclusive measurement with these polarized targets

# Technical Comments, part III

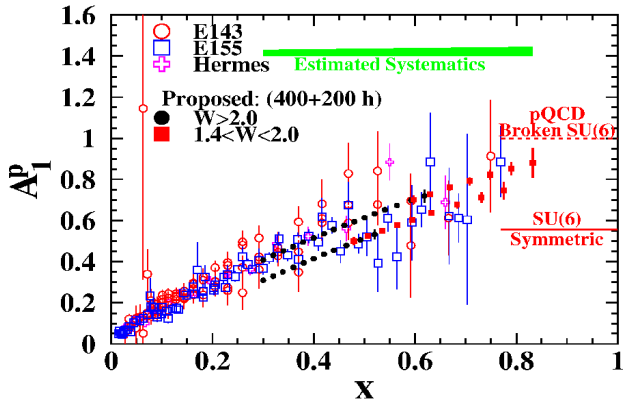
- The experiment will require a low current dump in the Hall for the non-parallel field measurements. This technique has before been used for the E93-026 experiment.
- The mentioned 2.5% uncertainty in target polarization should be substantiated. The collaboration is encouraged to look for techniques to monitor the product of beam and target polarization, e.g. by elastic scattering.

SLAC experiment E143, which uses the same target and polarization monitoring techniques, achieved a target polarization uncertainty of 2.4% on the proton with the NH3 target.

The elastic rates in BETA are too small to determine the beam polarization, not to mention uncertainties in $G_{Ep}/G_{Mp}$ at the covered $Q^2$ range. Most of the time, the HMS will be used to measure background rates and asymmetries. The balance of the time can be used to monitor the elastic asymmetries as a check on the independently measured beam and target polarization.

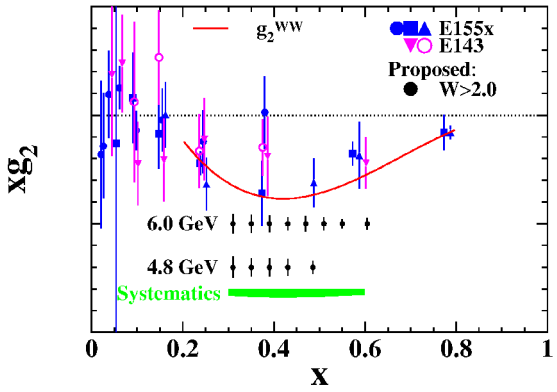


# $A_1^p$






# $g_2$






# BETA

Tracking Resolutions

| | |
|---|---|
| Angle | 2° |
| Vertex | 10 cm |

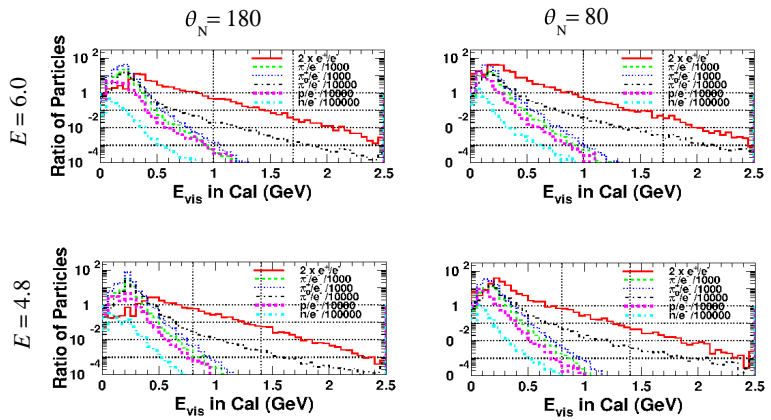
Reconstruction Resolutions

| | |
|---|---|
| Angle | 3-17 mrad |
| Momentum | 45-70 MeV |

Particle Rejection

| | |
|---|---|
| Pions | >1000 |
| Protons | >10000 |

# Background Studies






# Rates and Pileup in BETA

All Rates in kHz

| Gas Cerenkov | | | | Calorimeter | | | | |
|---|---|---|---|---|---|---|---|---|
| E | e± | π± | Trig | E | e± | π± | π0+N | Trig |
| 4.8 | 1.7 | 430 | 6.0 | 4.8 | 0.4 | 3.2 | 69 | 73 |
| 4.8 | 1.1 | 370 | 4.8 | 4.8 | 0.3 | 1.6 | 60 | 62 |
| 6.0 | 1.3 | 390 | 5.2 | 6.0 | 0.3 | 2.4 | 59 | 62 |
| 6.0 | 1.2 | 420 | 5.4 | 6.0 | 0.2 | 1.6 | 62 | 64 |

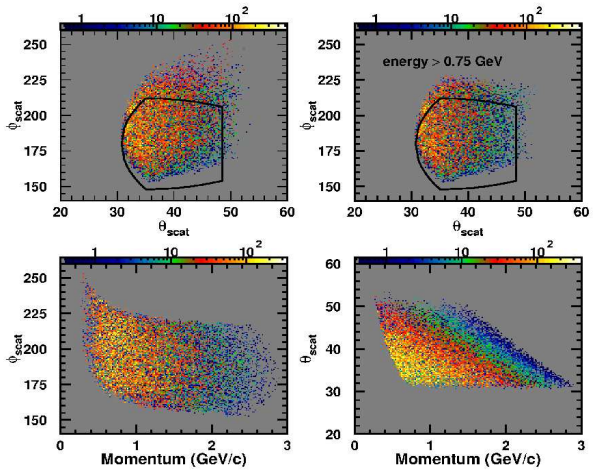
BETA Trigger Rates

| E | True | Accd |
|---|---|---|
| 4.8 | 0.40 | 0.09 |
| 4.8 | 0.29 | 0.06 |
| 6.0 | 0.33 | 0.06 |
| 6.0 | 0.24 | 0.07 |

⇒ Pileup with reasonable segmentation of calorimeter is low: ~0.2%

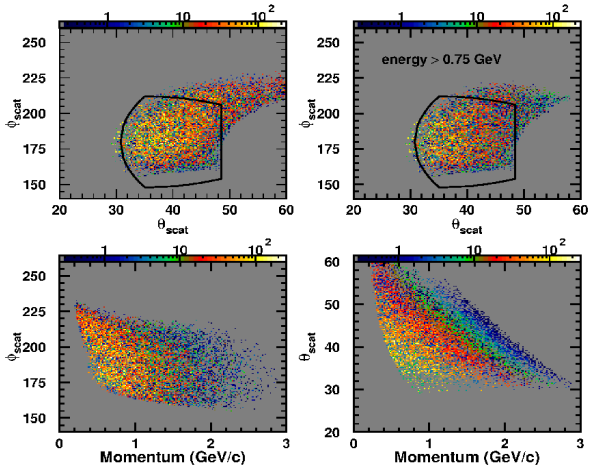


# Acceptance: E = 6.0, $\theta_N = 180$

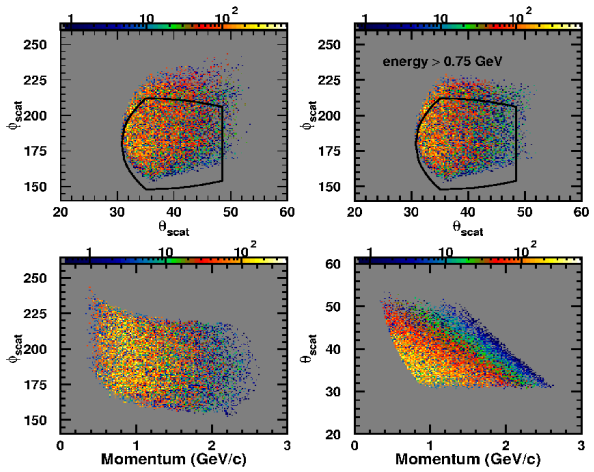





# Acceptance: E = 6.0, $\theta_N = 80$

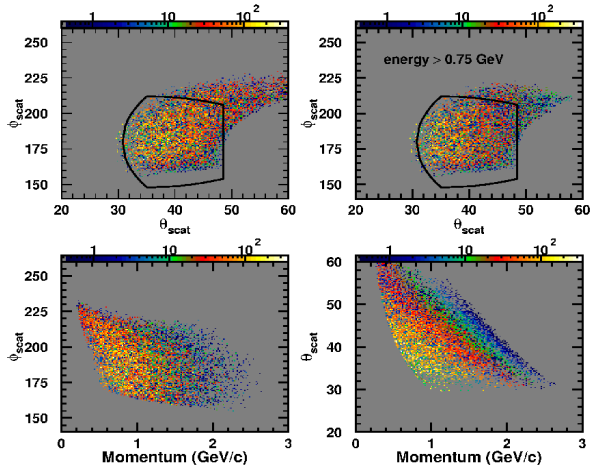


# Acceptance: E = 4.8, $\theta_N$ = 180






# Acceptance: E = 4.8, $\theta_N$ = 80






# BigBite and BETA

| | BigBite | BETA |
|---|---|---|
| **Solid Angle** | ~75 msr | 207 msr |
| **Detector Package** | Calorimeter<br>Gas Cerenkov<br>wire chambers (2) | Calorimeter<br>Gas Cerenkov<br>Lucite Cerenkov |
| **Dispersion** | Open Dipole | None |
| **Advantages** | Better Resolution | Built for high rates |
| **Disadvantages** | Interaction of fringe field with target field | |